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The Potential Effect of Partial Cutting and Thinning on Streamflow from the Subalpine Forest

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Abstract

Process studies suggest that thinning young lodgepole pine stands in Colorado and Wyoming significantly reduces winter interception loss. Soil moisture studies in lodgepole pine stands that range in basal area from 32 ft^2 to 180 ft^2 per acre, show that soil water depletion (and ET loss) is reduced and water available for streamflow is increased in direct proportion to the basal area reduced. However, because the subalpine environment is so precipitation limiting rather than energy limiting, the effect of basal area reductions on soil water depletion is eliminated in dry years.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

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Management Implications

Partial cutting has been thought to have little, if any, effect on streamflow (Leaf 1975, Troendle and Leaf 1980). This apparently is no longer correct. Thinning or reducing the overstory reduces winter interception loss and summer soil water depletion as efficiently per unit area as clearcutting, at least in wet years.

Procedures are available to estimate the effect of clearcutting on water yield in the subalpine (Bernier and Swanson 1986, Troendle and Leaf 1980). The soil water depletion patterns observed after partial cutting proportionally duplicate those for clearcutting and are a function of basal area removed. The modifier coefficients (weighted for percent basal area removed) presented in WRENSS (Troendle and Leaf 1980), combined with figure 8 to adjust the precipitation for interception savings, can be used as a first-generation management tool for simulating the effect of partial cutting on the water balance.

Although there still are several unanswered questions about the effect of partial cutting on water yield, there are several known facts. All harvesting has some effect. Clearcutting probably still represents the optimal strategy for increasing yield. Partial cutting, therefore, is likely to have a more limited effect. In some instances, it may be slightly more efficient than clearcutting; in other instances, such as in dry years, it will be less effective. Under average conditions, partial cutting probably is about as efficient as clearcutting, proportional to the percentage of total watershed basal area harvested. Response to partial cutting may even be more dynamic than clearcutting, because variations in elevation, aspect, and precipitation (and interactions) may have a greater effect on watershed response.

Introduction

Watershed experiments have shown that patch clearcutting the subalpine forest can increase streamflow significantly. Several plot and watershed studies also suggest that partial cutting or thinning can be equally as effective in changing the water balance, resulting in increased streamflow. Streamflow increased on watersheds in Colorado and South Dakota after 30% to 40% of the basal area was removed in shelterwood cuts. As with clearcutting, the greatest increases were associated with the wettest years.

Wilm and Dunford (1948) presented an early, definitive study of the effect of timber harvesting on the water balance of the lodgepole pine type. Five harvest plots representing a clearcut, a control, and three levels of partial cutting (0, 2,000, 4,000, 6,000, and 12,000 board feet per acre (bfa) reserve volume) were replicated in each of four randomized blocks. Using these plots, they drew several inferences about the effect of timber harvesting on the water balance of the lodgepole pine in the Colorado subalpine forest.

First, Wilm and Dunford (1948) noted that the snowpack water equivalent increased proportionally as the stand volume was reduced. Second, they found that net interception losses and soil water depletion were proportionally reduced. They concluded that water available for streamflow increased because of both winter and spring interception savings and summer evapotranspiration (ET) reductions. Most of the increase in water potentially available for flow was estimated to come from reductions in evaporative losses. Observed changes in soil water depletion were a minimal component (table 1).

Because clearcutting appeared to be more efficient in manipulating the winter snowpack and increasing water available for streamflow, much of the research in the subalpine forest zone has dealt with the effects of clearcutting on snowpack accumulation and water yield at the watershed level. Examples of these watershed studies are the Fool Creek and North Fork of Deadhorse Creek watersheds in Colorado (Troendle and King 1985, Troendle 1983a), and several watersheds on the James River and Marmot Creek in Alberta (Swanson and Hillman 1977).

Besides showing that the anticipated increases in flow after clearcutting actually occurred, the streamflow data allowed several other hypotheses to be tested. The increases in flow on Fool Creek (Troendle and King 1985), Deadhorse Creek (Troendle and King in press), and Wagon Wheel Gap (Troendle 1983a) are positively correlated with precipitation, implying greatest increases in wettest years. As observed by Wilm and Dunford (1948), Gartska et al. (1958), Orr (1969), and others, summer precipitation in the subalpine environment does not appear to contribute greatly to streamflow or to the change in streamflow after timber harvesting (Troendle and King 1985, in press; Troendle and Meiman 1986). Also, the effect of harvesting, at least clearcutting, appears to be very long-lived. Because there is considerable knowledge about the effect of clearcutting on various components of the water balance, techniques are available to predict its effect on the water balance (e.g., see Troendle 1983a, Bernier and Swanson 1986).

Although many watershed experiments address partial cutting (Bosch and Hewlett 1982), there are only two in the subalpine type environment. This paper first summarizes results of those experiments, and then presents several linear models that describe the interaction between growing stock level or stand basal area, precipitation (annual and seasonal), and site differences on the water balance of the subalpine forest.

Table 1.—Summary of the effect of different harvesting levels on the water balance of lodgepole pine (Wilm and Dunford 1948).

Lodgepole pine reserve volume	Increase[1] peak water equivalent	Increase[2] spring precipitation	Summer[3] interception reduction	Reduced soil water depletion	Net[4] ET reduction
bfa			*inches*		
12,7 (uncut)	0	0	0	0	0
6,000	0.8	0.3	0.6	0	1.1
4,000	1.0	0.5	0.8	0.5	2.0
2,000	1.5	0.2	0.9	0.4	2.1
0 (clearcut)	2.0	0.5	1.2	0.6	3.2

[1]*Net change in winter snowpack on April 1.*
[2]*Estimate of net increase in gross precipitation to the ground during melt period.*
[3]*Measure of interception savings lost to ET. Not included in ET savings.*
[4]*Sum of components, represents increase in flow.*

Effect of Partial Cutting on Watershed Response

Anderson (1980) reported the effect of a partial cut in ponderosa pine on the Sturgis experimental watersheds near Rapid City, S. Dak. Sturgis Watershed 3 is a 190-acre experimental watershed that flows to the north from an elevation of 5,700 feet and has a total relief of 700 feet. The basic hydrology, geology, and geomorphology of Watershed 3 and its 90-acre control, Watershed 2, were described by Orr (1969) and Yamamoto and Orr (1972).

After a 7-year calibration period, logging began on Watershed 3 in late summer 1970 and finished in 1971. The intent was to reduce the basal area on 130 of the 190 acres to a growing stock level (GSL) of 70. Postharvest surveys showed that although only about one-half the watershed area was harvested, approximately 25% of the total basal area on the entire watershed was removed.[2]

Preliminary results of the hydrologic response resulting from the timber harvest were presented by Anderson (1980). The average annual increase in flow was 1.9 inches ($P < 0.001$) for the years 1972–1979, with a yearly range from 0.6 to 3.8 inches. Forty-two percent of the increase occurred in April, 19% in May, and 25% in June, for a total of 86% in the 3-month runoff period.

For this paper, annual precipitation for Watershed 3 was divided into three seasonal values: winter (November-March), spring (April-June), and summer (July-October), and this precipitation parameter was correlated with the observed changes in flow, similar to the analysis used on the Fraser watershed data (Troendle and King 1985). During the 7 postharvest years, winter precipitation averaged 7.2 inches, with a standard error of 2.6 inches, spring precipitation averaged 13.7 ± 6.1 inches, and summer precipitation averaged 8.1 ± 2.4 inches. The mean precipitation for the watershed averaged 29.0 ± 4.6 inches per year.

Both in terms of total annual streamflow and change in flow after harvesting, spring precipitation was the parameter most significantly correlated with response.

[2]*Freeman Smith, personal communication.*

Winter precipitation, although significant ($P = 0.01$, $R = 0.50$), was only slightly correlated ($R = 0.10$) with both flow parameters. Summer precipitation was negatively correlated with both flow and the increase in flow ($R = -0.42$ and -0.50, respectively). However, because summer precipitation was equally negatively correlated with total annual and with spring precipitation, the postharvest summer precipitation (either expressed as current precipitation or lagged 1 year to represent previous or antecedent precipitation) was not correlated with either total flow or the change in flow. Summer precipitation ranged from 4.5 to 11.4 inches during postharvest years, and apparently was lost on site, with only minor contribution to flow.

More recently, a portion of the Deadhorse Creek watershed, Colorado, also was partially cut (Troendle and King, in press).

Deadhorse Creek is a 667-acre gaged watershed (fig. 1) that drains to the east, at elevations ranging from 9,500 to 11,670 feet. The two separately gaged subdrainages of Deadhorse Creek are the 100-acre North Fork and the 192-acre Upper Basin. The 120° V-notch streamgage on main Deadhorse Creek was built in 1955. The 90 weirs on the North Fork and Upper Basin were built in 1970 and 1975, respectively. The main watershed and two subdrainages are calibrated against a 1,894-acre control watershed, East St. Louis Creek, which has been gaged since 1943. Unit 8 is an ungaged, north-facing slope, also 100 acres, downstream from both the North Fork and the Upper Basin subdrainages. Unit 8 represents a portion of the 368-acre interbasin area below the two gaged subdrainages and above the main streamgage.

Forest cover on the Experimental Forest consists of spruce-fir stands along the stream channels, on north slopes, and at upper slope positions. Lodgepole pine grows on all low- and mid-elevation southerly or high-energy exposures. Alpine tundra is above timberline. There is an average of 12,000 board feet per acre of sawtimber on the forested portion of the Deadhorse Creek watershed.

Streamflow is monitored at each gage from mid-April to mid-October. Year-round measurement has been discontinued, because very little flow occurs during the winter, when streams usually recede to a reasonably constant base flow that approximates 0.2 cubic feet per second per square mile (cfsm). The measured flow includes all flow from mid-April, when the stream gages are opened, until mid-October, when they are shut down. Winter baseflow is not included in the estimate of annual yield. Snow courses, to index peak water equivalent; precipitation; temperature and humidity; and annual sediment export also have been continuously monitored. Comparative snow course observations between the Deadhorse Creek and East St. Louis Creek, begun in spring 1967, were used to estimate the mean water equivalent for each of the watersheds. Samples (118) of snow water equivalent were collected at 132-foot intervals on Deadhorse Creek, along transects that cross all major slope aspects and elevations.

In 1980 and 1981, Unit 8 (North Slope, fig. 1) was harvested in the first step of a 3-step shelterwood cut. Approximately 40% of the basal area was removed as individually marked trees 7 inches d.b.h. and larger. Unlike the North Fork and Upper Basin subdrainages, the partially cut Unit 8 portion of Deadhorse Creek is not independently or directly gaged. Therefore, the annual flow of the Upper Basin and the North Fork must be subtracted from the total flow at the main gage for the watershed to partition out the flow from the interbasin area, which includes the contribution from Unit 8. Partitioning the flow increases the opportunity for error and decreases the reliability of the experiment, but must be done for two reasons.

1. Unit 8 is only 100 acres, while the entire Deadhorse drainage is 667 acres. Any impact restricted to the Unit 8 would be less likely to influence total flow detectably than it would be to influence the partitioned interbasin flow.
2. The North Fork subdrainage, also 100 acres, was harvested 3 years before Unit 8. Partitioning allows removal of the effect of that treatment on flow at the main weir.

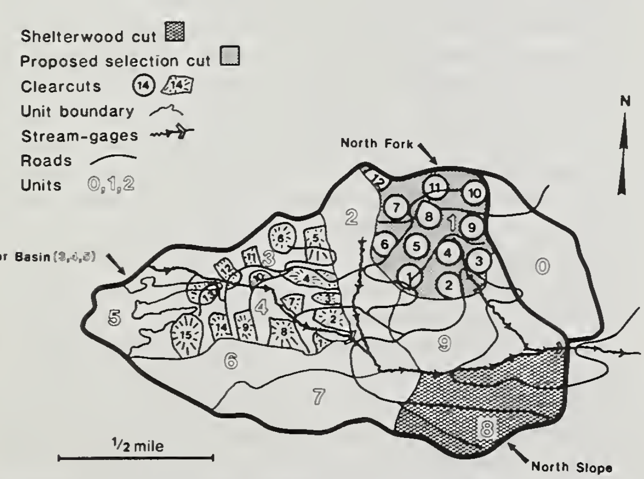

Figure 1.—The Deadhorse Watershed showing the North Fork and North Slope harvest units.

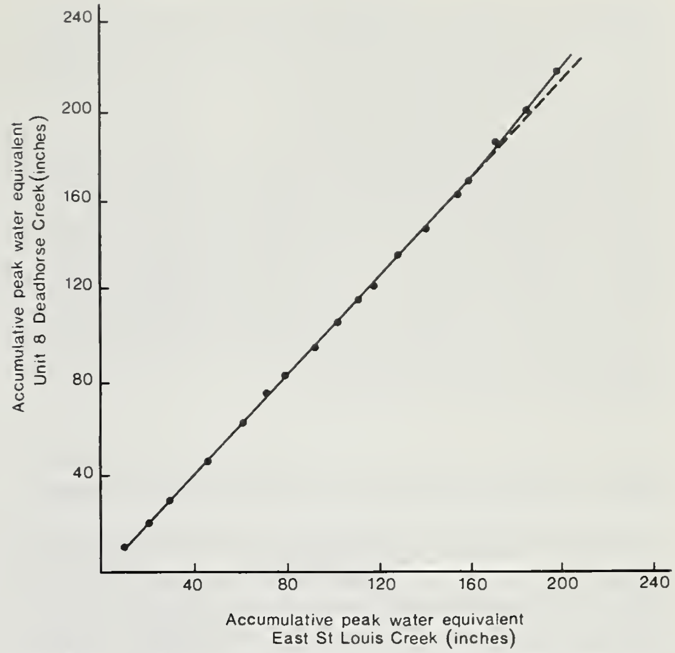

Figure 2.—The effect of a partial cut on accumulative peak water equivalent, North Slope, Deadhorse Creek.

Partitioning was done for total annual flow only, with no attempt made to isolate peak flow rates or timing of peak, for the interbasin area. The partial cut affected both winter snowpack accumulation and streamflow. Unlike the North Fork, however, covariance analysis of the pretreatment and posttreatment regressions showed a significant increase ($P = 0.002$) in the adjusted mean water equivalent over the entire Unit 8 after timber harvest. Peak water equivalent, when compared with the control, increased 1.9 inches or 16% over the entire 100-acre unit. The increase is shown in the double mass plot of figure 2. The net increase in accumulation on the Unit 8 (North Slope) probably reflects an interception savings, because the increase there cannot be correlated with a decrease elsewhere either in the Deadhorse Creek watershed or on nearby Lexen Creek.

Other research (Gary and Troendle 1982; Gary and Watkins 1985; Troendle and King 1985; Troendle and Meiman 1984, 1986) showed that, along with any redistribution effect in clearcuts, there also is a reduction in interception loss after harvesting. The result can be a net increase in peak water equivalent on the watershed under either clearcut or partial cut conditions.

Covariance analyses of the adjusted group means for the 6 pretreatment and 3 posttreatment years suggested that flow from the entire interbasin area may have increased 1 inch ($P = 0.34$) after partial cutting. This represents a unit area increase of 3.6 inches from the 100-acre area harvested. Because the posttreatment record years were well above average in precipitation, the estimated increase probably is larger than what might be expected in drier years. The hypothesis of establishing the treatment, however, was that partial cutting applied to the area would have no effect on water yield under any circumstances. Because 1.9 inches of the estimated 3.6-inch increase in flow can be attributed to the significant increase in snowpack, the estimated increase in flow,

although not statistically significant, appears realistic. Also, the observed response occurred from a north-facing slope, and the efficiency may be greater than what could be expected from other aspects.

The Fraser watershed data, like the Sturgis data, suggest that partial cutting increases flow, and that both total flow and the increase in flow are dominated by winter and spring climatic conditions. However, the limited watershed data presented here are not adequate to develop generalizations or models of hydrologic response, because they do not represent an adequate range in basal area reductions. Inferences about the influence of a continuum of basal area levels must be drawn from various plot studies that are available.

Effect of Partial Cutting on Summer Water Balance

In 1975, a study was started in 60- to 70-year-old lodgepole pine on the Fraser Experimental Forest, Colorado, to test the effect of different thinning levels (GSL) on subsequent growth (Alexander et al. 1985). The study area was divided into five blocks, with one block thinned each year. Within each block, four 0.4-acre plots were thinned from below, each to a different growing stock level (GSLs 40, 80, 100, 120). The first series of plots in block 1 were thinned in 1976, the last series of plots in block 5 were thinned in 1980. Additional plots in blocks 2, 3, and 4 were added in 1981 and thinned to GSL 160. Adequate stands for GSL 160 were not found in blocks 1 and 5.

In 1975, four neutron-probe access tubes were installed to a depth of 5.5 feet in each GSL plot, and on the single control plot in block 2. They were installed later on the 160-level plots selected in 1981. Soil moisture measurements were taken at 6-inch-depth intervals periodically during each growing season from 1976 to 1983. The intent was to measure the plots as early as possible after snow melt (recharge) and then again at the end of the growing season (maximum depletion). The objective of the study was to define the differences in soil water depletion that occur during the growing season as a function of basal area, block or site differences, and years or climatic differences. One obvious problem with the experiment is that in block 1 there was no calibration or pretreatment data, only 7 years of posttreatment record, whereas on block 5 there were 5 years of pretreatment and 2 years of posttreatment data. All years differed climatically.

Linear regression techniques were used to evaluate causal relationships that exist between the rate of change (±) in soil moisture per unit time (dependent variable) and basal area, block or site, midpoint date of the measurement interval, and precipitation during the measurement interval.

Growing season precipitation is used primarily on site and does not appear to make a detectable contribution to streamflow (Orr 1969; Troendle and King 1985, in press; Troendle and Meiman 1986). Therefore, a second dependent variable, daily evapotranspiration, was calculated. This was estimated as the sum of the soil water depletion between two successive measurements and the precipitation that fell during the interval, divided by the number of days in the measurement interval. At the plot level, this number represents the best estimate of average daily water use (ET) for the measurement interval.

Daily soil water depletion was regressed on daily precipitation, basal area, date (from January 1 until the midpoint of the measurement interval), and block or site. Basal area was the least significant of the independent variables ($P = 0.01$). When the same regression was fitted for each of the individual years, the significance of basal area in the equation depended on whether it was a wet or dry year. In dry years, basal area was not related significantly ($P = 0.50$) to daily soil water depletion. Figures 3 and 4 represent plottings of daily soil water depletion over basal area for years 1980 (dry) and 1983 (wet), respectively.

In 1980, when only 4.5 inches of precipitation fell during the growing season measurement period (July 7 to October 8), basal area was not significantly correlated with soil water depletion. In 1983 (fig. 4), 9.3 inches of precipitation fell from July 12 to October 8, and soil water depletion was significantly correlated with basal area ($R=0.4$, $SE = 0.02$ in). Figure 5 represents a similar plotting for all years of record. Basal area is significant when regressed on soil water depletion ($P = 0.001$, $R=0.22$, $SE=0.02$ in), but it is apparent in figure 5 that there is much variation about the line that cannot be accounted for by basal area alone.

Because each year of the study was different climatically, and because all plots were not treated under the same climatic conditions, it is impossible to present an average soil water depletion curve for each GSL or basal area. Based on the average relationship between basal area and soil water depletion shown in figure 5, a reduction in basal area from 160 to 32 would result in a 2-inch reduction in soil water depletion between June 15 to October 15.

In the previous example for the North Slope portion of Deadhorse Creek (the partial cut), basal area was reduced 35% to 40% or from 180 ft^2 per acre to 120 ft^2 per acre. Estimating the difference in use from figure 5, the reduction in soil water depletion would be 1-inch for the growing season. As noted earlier, there was also a 1.9-inch increase in water equivalent in the spring snowpack on the North Slope. The 1-inch average savings during the 4-month portion of growing season seems reasonable, considering the total increase in flow was estimated to be 3.6 inches at the streamgage. Because any savings in April and May are not included, the combination of the 1.9-inch winter interception savings and 1.0-inch summer depletion savings represents a reasonable portion of the total (2.9 of 3.6 inches).

As noted previously, total evapotranspiration for each soil moisture interval can be estimated by summing the precipitation that fell during the interval with soil moisture depletion (±) that occurred. This sum represents the maximum amount of water available for ET and includes any water lost to deep seepage or streamflow. However, because summer precipitation is not signif-

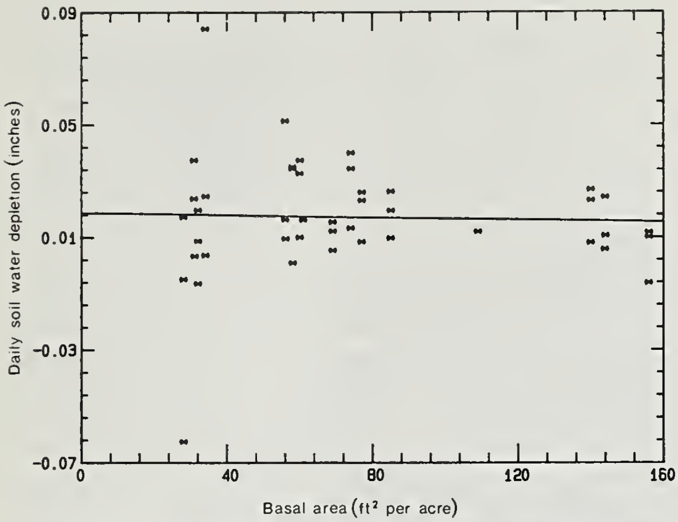

Figure 3.—The effect of basal area on soil water depletion, dry year 1980.

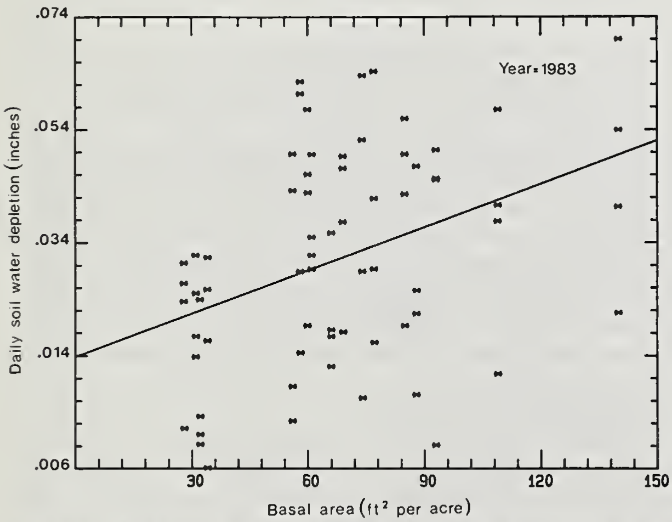

Figure 4.—The effect of basal area on soil water depletion, wet year 1983.

icantly correlated with change in flow, summer precipitation is presumed to be retained on site, thereby reducing soil water recharge requirements (and apparent depletion) or evaporation. Soil water depletion differences between the different basal area levels reflects the net effect of the ET changes. Daily ET rates were not presented in a format similar to the daily soil water depletion rates, because the soil water depletion best expresses the change caused by basal area reduction. ET averaged 0.14 to 0.17 inches per day.

Kaufmann et al. (1982) presented equations for converting stand basal area to leaf area index or transpiring surface. Figure 6 represents a plotting of the ratio of daily ET expressed per unit of leaf area to basal area of the stand. It notes the exponential decrease in water use that occurs per unit leaf area as the basal area (and leaf area) is decreased. It does not necessarily imply greater transpiration occurs at lower basal area levels; but it reflects that, in the water-limiting summer environment of the subalpine, precipitation water is vaporized almost regardless of vegetal density. Many factors are involved

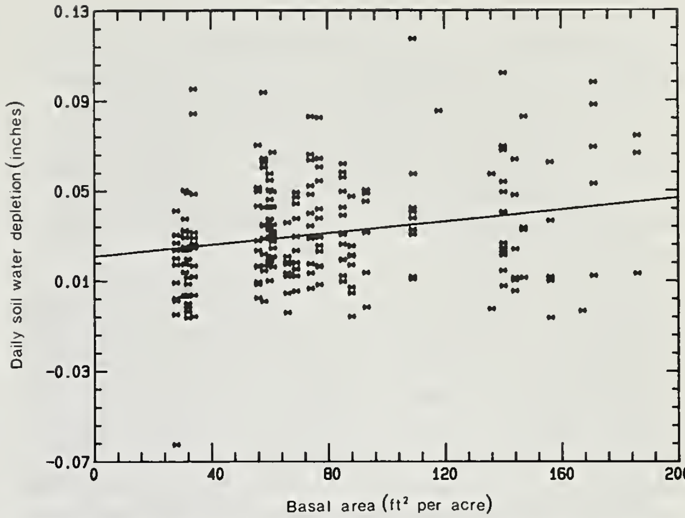

Figure 5.—Relation between daily soil water depletion and basal area, all data.

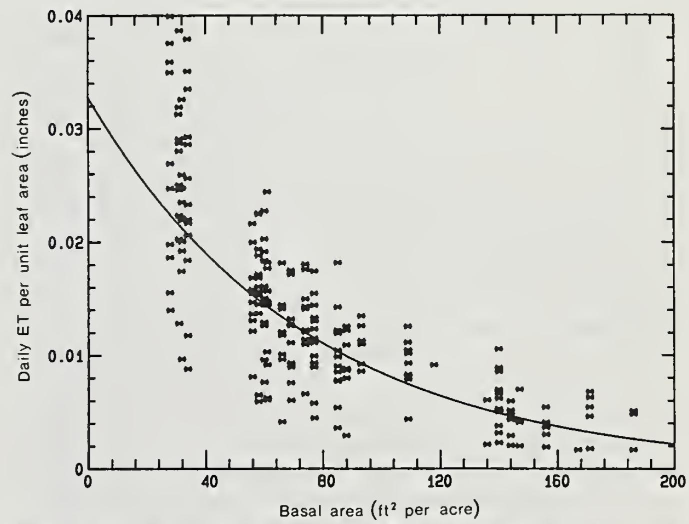

Figure 6.—Relation between daily ET (soil water depletion plus precipitation) per unit leaf area and stand basal area.

in the ET process, and figure 6 does not represent an empirical ET model. It shows that a certain degree of evaporative compensation occurs as the basal area is reduced.

Soil moisture studies, such as this one and others in the subalpine (Potts 1984, Troendle and Meiman 1986), are not designed to estimate ET, although the estimates of daily use appear to be good. The strength of these studies is in their definition of the soil water deficits in the fall as a function of basal area. These recharge differences reflect the effective net change in the ET processes (pertaining to flow) that result from the change in growing stock levels. These differences are the net effect that is passed on to the increase in flow that occurs when recharge begins.

Effect of Partial Cutting on Snowpack Accumulation

As table 1 showed, Wilm and Dunford (1948) defined linear increases in snowpack accumulation after timber

harvesting. Gary and Troendle (1982), reporting on partially cut lodgepole pine stands in both Colorado and Wyoming, also showed linear increases after different levels of partial cutting. Gary and Watkins (1985), in a separate Wyoming study, noted that peak water equivalent increased 2 inches or 30% in a thinned stand of doghair lodgepole pine. This increase occurred with no detectable impact on snow in the upwind or downwind control forest.

Figure 7 represents a plotting of average peak water equivalent increases for the growing stock level plots at Fraser Experimental Forest. Superimposed on the curve are the mean increases for the three levels of harvest in the lodgepole pine harvest plots reported by Wilm and Dunford (1948). Both data sets show a similar trend of increased water equivalent with reduced basal area. Because the initial basal area on the harvest plots (Wilm and Dunford 1948) averaged 15 square feet per acre greater than the initial basal area on the GSL plots (155 versus 140), the relative reduction in basal area was greater on the harvest plots, as was the increase.

Figure 8 represents a plotting of the average increase in peak water equivalent over the percent basal area removed for some studies in the lodgepole type. Each data point on figure 8 represents the average value for that plot for the length of the respective study; individual yearly values were not used. The data include the lodgepole pine harvest plots in Colorado (Wilm and Dunford 1948); the lodgepole pine GSL plots in Colorado (Troendle and Meiman 1984); the North Slope partial cut, Deadhorse Creek, Colorado (Troendle and Meiman 1984); the lodgepole pine thinning plots in Wyoming (Gary and Troendle 1982, Gary and Watkins 1985); and a small clearcut in Colorado (Troendle and Meiman 1986). Several other studies in the United States and Canada show similar results for clearcut situations. Also plotted, but not included in the fitting of the regression line, are the mean increases for the commercial clearcuts on both Fool Creek and Deadhorse Creek in Colorado (Troendle and King 1985, in press).

Although there is significant variation in the fit of the relationship presented in figure 8, the R^2 of 0.73 (P = 0.001 for B_1 and 0.00002 for B_2) implies a strong correlation between percent reduction in basal area and increase in peak water equivalent over the entire range in basal area. In most cases, the plot means for peak water

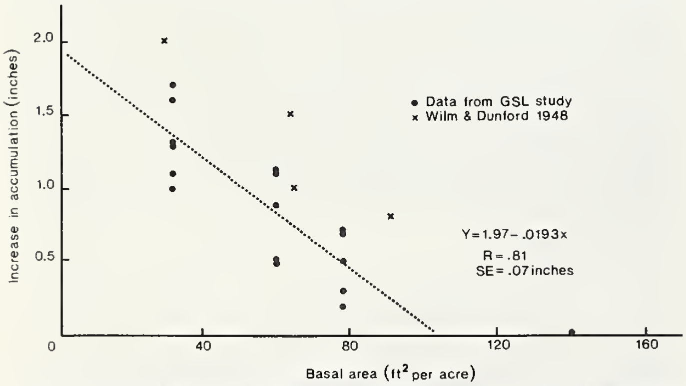

Figure 7.—Relation between increase in snowpack water equivalent increase and basal area.

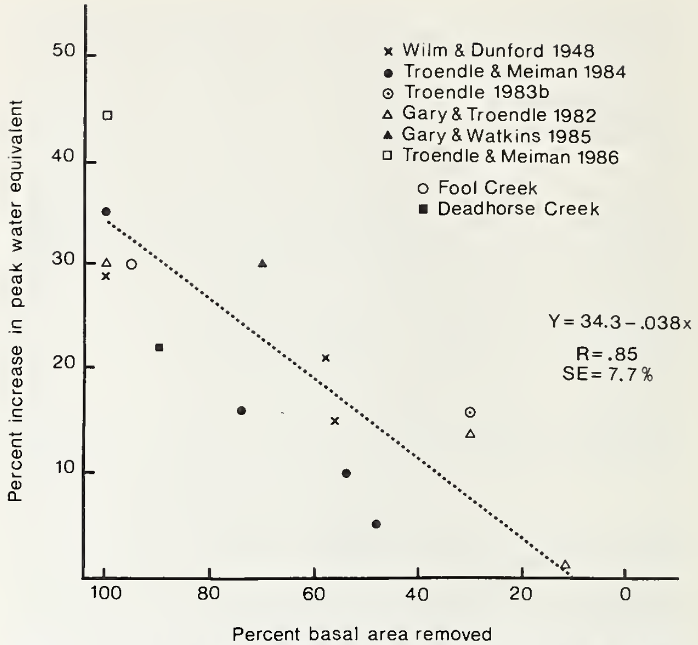

Figure 8.—General relationship of percent increase in water equivalent as a function of basal area removed.

equivalent ranged from 7 to 14 inches, with the observed range in yearly peak water equivalent for each plot varying from 2.6 to more than 17 inches. The increase in accumulation, particularly in the mid- to lower range of basal area reductions, reflects an interception savings that, in most years, should be directly translated to an increase in flow. Because figure 8 represents a regional average response, it can be used for that purpose with existing predictive techniques, as long as the user realizes it applies to the average.

Potts (1984) reported on a lodgepole pine spacing study in western Montana. In that continental environment, the winter snowpack is more intermittent and, in his observations, peaked on December 31. Although Potts measured depth rather than water equivalent, the proportional differences in snow depth attributable to basal area differences he presented appear consistent with the relationship presented in figure 8.

One significant observation about the relationship depicted in figure 8 is the consistency with which the observations for clearcuts fit the general curve for partial cuts. Several authors have concluded that much of the increase in accumulation in clearcuts largely represents an interception rather than a redistribution phenomenon. Figure 8 tends to confirm that conclusion.

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Process studies suggest that thinning young lodgepole pine stands in Colorado and Wyoming significantly reduces winter interception loss. Soil moisture studies in lodgepole pine stands that range in basal area from 32 ft^2 to 180 ft^2 per acre, show that soil water depletion (and ET loss) is reduced and water available for streamflow is increased in direct proportion to the basal area reduced. However, because the subalpine environment is so precipitation limiting rather than energy limiting, the effect of basal area reductions on soil water depletion is eliminated in dry years.

Keywords: hydrologic balance, thinning, partial cutting, snowpack accumulation, water yield

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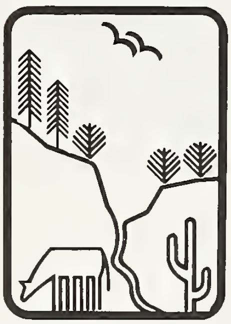
Rocky
Mountains



Southwest

Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526